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MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 85
Number 2

FEBRUARY 1957

Closed April 15, 1957
Issued May 15, 1957

SOME STATISTICAL ASPECTS OF CIRRUS CLOUD

J. CLODMAN

Research and Training Division, Meteorological Service of Canada, Toronto
[Manuscript received December 26, 1956; revised March 28, 1957]

ABSTRACT

A large body of aircraft reports is analyzed to provide information on the vertical and horizontal distribution of cirriform clouds in Canada. Other parameters are investigated including temperatures at the base of cirrus cloud, relationship of cloud tops with the tropopause, stratospheric cirrus, and visibility in cirriform clouds.

1. INTRODUCTION

This investigation grew out of a need for information on high-level clouds and visibilities. It was readily apparent that data based on surface observations would be highly inadequate. Much cirrus [1] cannot be seen from the ground either because it is too tenuous or because lower clouds are interposed. Surface estimates of cirrus heights are often grossly in error [1], and there is no way of estimating the depths of cloud layers from such observations. Many of the difficulties can be circumvented by the use of aircraft observation. A body of observations was available which had been taken by Royal Canadian Air Force pilots when engaged in routine flights. These reports are not made in any standard fashion and therefore vary considerably in accuracy. However the reporting errors involved are, for the most part, random in nature. About 2,500 such reports were analyzed for the purposes of the present investigation. The observations covered the period 1950–1956 although the majority were made in the years 1953–1956.

Over 2,000 of the reports were analyzed to determine the percentage occurrence of cirrus at 30,000 ft., 35,000 ft., 40,000 ft., and 50,000 ft. Only one case of cirrus was encountered at 50,000 ft. so that no tabulation was kept for this height. The percentages were arrived at by considering each flight as a sample of the atmosphere and noting the portions of the sky covered by cirrus at the levels in question. In addition, a parameter which shall be referred to as "Total Cirrus" was also tabulated. This parameter indicates the percentage of the sky covered by cirrus, regardless of altitude or number of layers involved. It, therefore, corresponds to the figure of cirrus amount which would be reported by an observer on the ground if the lower cloud were transparent and the observer could detect all of the cirrus present.

Some 400 additional aircraft reports were analyzed separately for information on the base and tops of cirrus layers. In this analysis, temperature and tropopause values were deduced from radiosonde data and upper-air charts.

Murgatroyd and Goldsmith [2] and more recently James [3] carried out investigations on cirrus cloud over the British Isles, based on a more limited number of aircraft observations. Certain items such as heights of clouds and relationship of cirrus to the tropopause were investigated in the British papers and their results did not seriously differ from those reported here.

2. SOURCES OF ERRORS IN THE ANALYSES

The individual height and temperature values are subject to fairly substantial measurement errors. However, it is hoped that these errors are essentially random in nature and thus will not significantly affect the statistical results.

The samples used are, for the most part, large enough to give reasonably representative figures. However, in

[1] In this report the terms cirrus and cirrus cloud are used interchangeably with cirriform cloud.

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TABLE 1.—*Cirrus amounts as related to undercast and precipitation*

	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
Unspecified cases	15.7	7.6	2.2	32.6	518
With undercast	25.3	9.6	1.8	44.9	565
With precipitation	38.7	15.3	2.1	59.6	94
Without undercast	8.7	4.4	1.8	20.9	912
Mean	15.2	6.7	1.9	30.7	1,995

TABLE 2.—*Cirrus amounts for specified geographic locations*

Area	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
North Bay	14.8	6.1	1.6	30.3	1,423
Prairies	14.5	10.0	4.2	29.1	173
Eastern Canada	16.8	7.4	1.9	33.0	399
Mean	15.2	6.7	1.9	30.7	1,995

TABLE 3.—*Cirrus amounts for various times of year*

Period	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
Warm months	18.4	10.2	3.6	31.8	626
Intermediate months	15.7	7.4	1.3	31.9	690
Cold months	11.8	2.8	0.9	28.7	679
Year	15.2	6.7	1.9	30.7	1,995

TABLE 4.—*Corrected cirrus amounts for various times of year*

Period	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
Warm months	18.8	10.4	3.7	32.4	626
Intermediate months	16.0	7.6	1.3	32.6	690
Cold months	12.8	3.0	1.0	31.2	679
Year	15.6	6.9	2.0	31.8	1,995

common with other data of a climatological nature, there is always the possibility of even a large sample being abnormal. Nonetheless, certain internal checks indicate that most of the results are fairly stable.

There are some biases in the data which could affect the results. For example, reports of cirrus which did not specify heights had to be rejected. Since nil reports are not involved in these rejections, this reduces the calculated percentage occurrence of cirrus. On the other hand, pilots report occurrences of phenomena more faithfully than non-occurrences. This preference results in an error in the opposite sense and so may compensate for the first bias. In any case, a study of the order of magnitude of these errors indicates that they are not large so that their net effect can fairly safely be ignored. As a result of reporting errors there may have been some clouds included which were actually not cirriform. Ludlum [4] indicates that somewhere between −10° C. and −30° C. ice cloud rather than water cloud becomes the stable form. It was therefore decided to reject all clouds whose base was warmer than −20° C. If some cirrus was thereby rejected, it was hoped that this would counterbalance the failure to reject other non-cirriform cases. However, only a limited number of cases are involved so that this rough assumption will not seriously affect the results.

3. VARIATION OF CIRRUS AMOUNTS WITH UNDERCAST AND PRECIPITATION

Cirrus cloud will be more prevalent in areas of large-scale ascending motion. Thus, there should be increased amounts of cirrus when lower cloud layers and precipitation are present. Accordingly, the reports were subdivided into: (a) unspecified cases, (b) cases with an undercast, (c) cases with precipitation, (d) cases without an undercast. It should be noted that the instances with an undercast include those with precipitation. Table 1 lists the mean percentages of the sky covered by cirrus under the various conditions. We see that the distribution for the "unspecified cases" is similar to the overall distribution. Since the unspecified cases were arrived at by a random process this suggests that the results are dependable.

4. GEOGRAPHIC VARIABILITY OF CIRRUS

The reports were subdivided into the following three geographic areas: (1) Eastern Canada (southern Quebec and New Brunswick), (2) Prairies (Alberta, Saskatchewan, and Manitoba), (3) North Bay area (in Ontario). Table 2 lists the percentage occurrence of cirrus for each of these areas. There does not appear to be much geographic variability, particularly if we bear in mind that the Prairie figures are based on a relatively small sample. It would be unsafe to assume that the homogeneity indicated by table 2 extends to regions with radically different climatic regimes.

5. SEASONAL VARIABILITY OF CIRRUS

An analysis was carried out to see whether there was any seasonal variation in the occurrence of cirrus. Table 3 lists the results of this analysis where the "warm months" refer to June, July, August, and September; the "intermediate months" are March, April, May, and October; and the "cold months" November, December, January, and February.

Although there are differences between the seasons in the vertical distribution of cirrus, the "Total Cirrus" amounts do not vary a great deal. The cold months show a somewhat lower figure but there is a correction to be applied before this reduced amount can be accepted as real. The necessity for this correction stems from the fact that there is more bad flying weather in winter than in other months although there are increased cirrus amounts associated with bad weather. In order to calculate the magnitude of this effect, the percentage occurrences, for each of the periods, of either ceilings below 500 ft. or visibilities below one mile were determined from climatological records [5] and it was considered that there would be no flying under such circumstances. It was then assumed from table 1 that the "Total Cirrus" was

TABLE 5.—*The base and tops of cirrus layers (thousands of feet)*

(a) According to Seasons

Season	Base	Top	H_{max}
Warm months	28.5	33.5	31.0
Intermediate months	25.5	30.1	27.8
Cold months	24.5	29.4	26.9
Year	26.2	31.0	28.6

(b) According to Cirrus Amounts

Cloud amount	Base	Top	H_{max}
Overcast	24.8	33.0	28.9
Broken	25.0	30.0	27.5
Scattered	26.7	29.3	28.0
Mean	25.5	30.8	28.1

NOTE: H_{max} is midway between the mean top and bottom of the cloud.

TABLE 6.—*Thickness of cirrus layers (thousands of feet)*

Season	Top minus base from table 5a	From areas of figure 1	By using 400 check reports
Warm months	5.0	6.5	6.7
Intermediate months	4.7	6.0	6.3
Cold months	4.9	5.6	6.0
Year	4.9	6.0	6.3

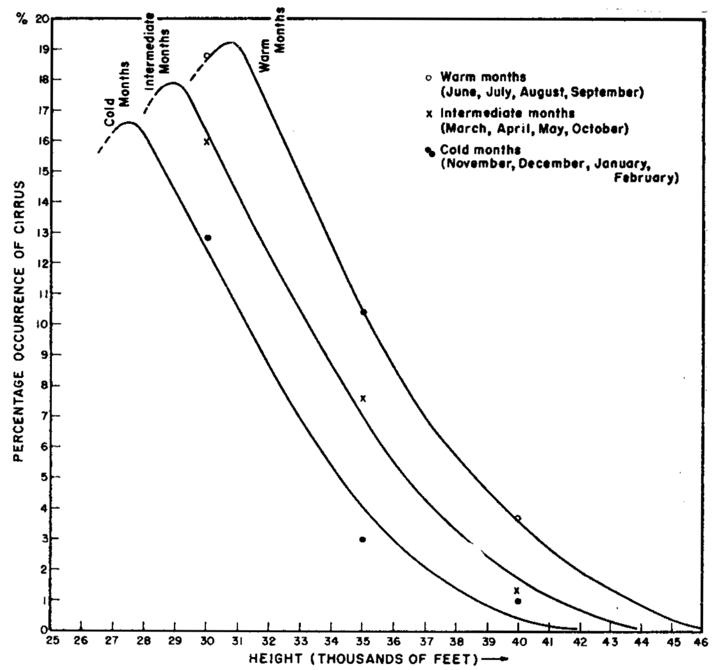

FIGURE 1.—Percentage occurrence of cirrus versus height, for various seasons.

45 percent for the portion of the time when flying conditions were poor and 30 percent at other times. It was thus possible to arrive at the figures of table 4 which removed the bias due to the fact that more flying takes place in relatively good weather. Although the corrections are small they reduce the differences in the "Total Cirrus" percentages between the cold months and the other months. Comparing the yearly values in tables 3 and 4 it appears that a correction of about one part in thirty could be applied to the percentages of tables 1 and 2 to allow for this effect.

6. THE BASE AND TOP OF CIRRUS

An independent group of over 400 North Bay reports was analyzed with reference to the base and tops of cirrus layers and some of the results of this analysis are incorporated in table 5. The level of maximum occurrence of cirrus, H_{max}, is also listed and this is taken as the level midway between the mean top and bottom of the cloud. The mean values in the two parts of table 5 are not identical since some reports did not specify cloud amounts.

7. VERTICAL DISTRIBUTION OF CIRRUS

Using the percentages of table 4 and the heights of maximum occurrence of cirrus from table 5(a), the upper halves of the curves of percentage occurrence of cirrus versus height were drawn as shown in figure 1. The problem of a unique interpretation of the data was reduced by assuming that the curves for the three parts of the year were fairly similar and parallel. Since this realistic assumption can be made without significantly violating the data, we can conclude that the distributions are reasonably dependable.

8. THICKNESS OF CIRRUS LAYERS

The mean thicknesses of cirriform layers can be derived by subtracting the mean heights of the base from the tops using the values of table 5 (a). Also, on the assumption that there is as much cirrus below the height of maximum occurrence as above, mean thicknesses were obtained using the curves of figure 1 and the "Total Cirrus" percentages. About 400 of the original body of 2,000 reports could be analyzed for cloud thickness and this was done. These three sets of thickness values are listed in table 6. The figures based on the data of table 5 (a) are somewhat lower than the others. However, these results were based on an independent body of reports and the sample may have been somewhat abnormal. The good agreement between the other two sets of values suggests that the frequency distributions of figure 1 are reasonable and that the effects due to contamination of the data by non-cirriform clouds are negligible.

9. TEMPERATURES AT THE BASE OF CIRRUS

The formation of cirriform clouds usually takes place on ice nuclei and these become active over a fairly wide temperature range. It has been suggested (see, for example, Ludlum [4]) that below a temperature of about −40° C. there is a rapid increase in the number of active nuclei. If this is correct the temperature at the base of cirrus may tend toward this value. Thus, the distribution of mean cirrus-base temperatures versus height may differ significantly from normal temperature-height distributions and it would be feasible to use cirrus-base temperature-height curves to estimate or forecast the base of cirrus cloud. Appleman [1] suggested the use of his con-

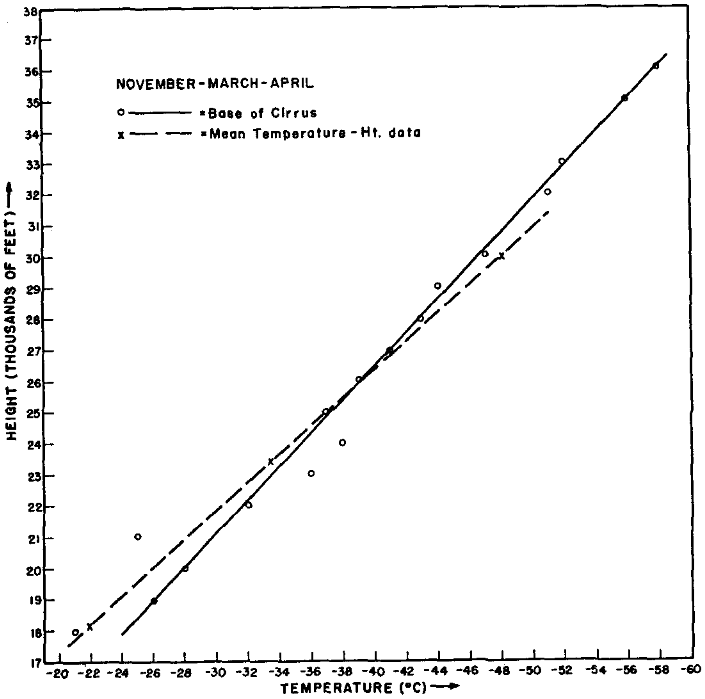

FIGURE 2.—Comparison between temperature-height distribution of base of cirrus and mean temperature-height data for all days in November, March, and April.

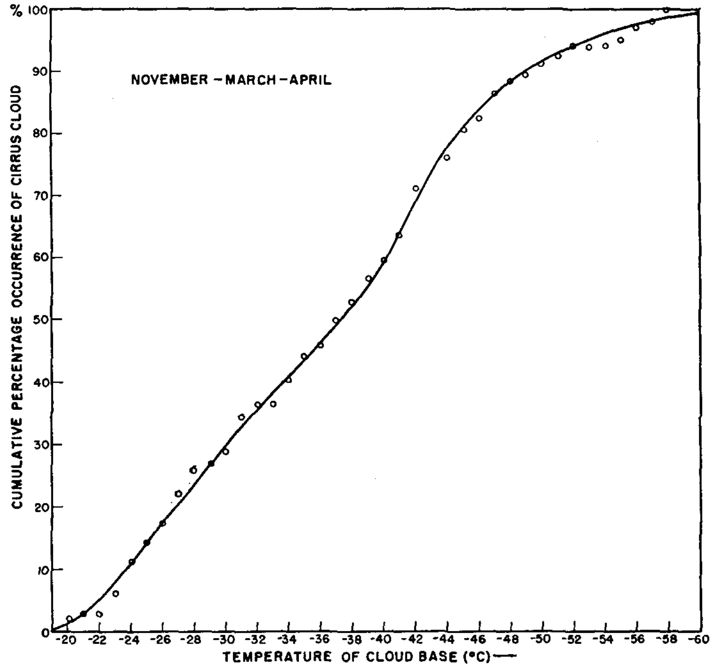

FIGURE 3.—Ogive giving cumulative percentage occurrence of cirrus versus temperature of cirrus base.

trail forecasting curves for this purpose. These curves are approximately in the proper temperature range and thus could prove useful in this connection although, on the average, they would necessarily give larger errors than mean cirrus-base temperature-height curves.

In order to investigate the feasibility of this technique, curves were drawn giving the mean temperatures at the base of cirriform cloud versus height for four groups of months. Mean temperature-height data [6] were used to draw comparison curves. The results for November-March-April are typical and these are shown in figure 2. These curves indicate that the temperature-height distribution of the base of cirrus is not sufficiently abnormal to be of much practical use. However, the temperatures at which the curves intersect are of some theoretical interest and these are listed in table 7. The intersections are somewhat ambiguous so that the results are only approximate. Table 7, however, indicates that the temperatures at the base of cirrus are somewhat closer to −40° C. in the mean than is normal for the given height.

Even though cirrus-cloud bases are found over a near-normal temperature range it is possible that a high proportion of cirrus forms with its base near −40° C. and is

TABLE 7.—*Intersections of cirrus-base temperature-height curves with normal temperature-height curves*

Season	Temperature (°C.)
Dec-Jan-Feb	−40
Nov-Mar-Apr	−39
May-Sept-Oct	−43
June-July-Aug	−37
Mean	−40

TABLE 8.—*Base temperatures associated with maximum occurrence of cirrus*

Season	Temperature range (°C.)
Dec-Jan-Feb	−37 to −42
Nov-Mar-Apr	−40 to −45
May-Sept-Oct	−40 to −44
June-July-Aug	−28 to −33
Mean	−39

TABLE 9.—*Distribution of tropopause-cirrus tops separation*

(a) According to Seasons

Tropopause minus cirrus tops (1000's of ft.)	Warm months (%)	Intermediate months (%)	Cold months (%)	Year (%)
−5.0>	2	1	1	1
−5.0 to −2.1	2	3	2	2
−2.0 to −0.1	7	6	15	9
0 to +2.0	22	19	27	22
+2.1 to +5.0	31	27	24	27
+5.1 to +10.0	24	28	26	26
>+10.0	12	17	4	11
Mean (1000's of ft.)	4.5	5.4	3.4	4.4

(b) According to Cirrus Amounts

Tropopause minus cirrus tops (1000's of ft.)	Overcast (%)	Broken (%)	Scattered (%)	Mean (%)
−5.0>	0	2	1	1
−5.0 to −2.1	2	0	4	2
−2.0 to −0.1	16	10	5	10
0 to +2.0	32	19	18	23
+2.1 to +5.0	25	31	30	29
+5.1 to 10.0	21	25	24	23
>+10.0	4	12	18	12
Mean (1000's of ft.)	3.1	4.6	5.4	4.4

TABLE 10.—*Stratospheric cirrus (heights in thousands of feet)*

	Month	Base	Top	Tropopause	Base minus tropopause	Top minus tropopause	Cloud amount	Tropospheric airmass
1	Jan	30.0	35.0	30.6	−0.6	4.1	Scattered	maritime Polar
2	Jan	32.0	------	30.5	1.5	------	Scattered	maritime Arctic
3	Jan	20.0	38.0	36.0	−16.0	2.0	Overcast	maritime Polar
4	Feb	35.0	38.0	35.5	−0.5	2.5	Scattered	maritime Arctic
5	Mar	34.0	39.0	35.6	−1.6	3.4	Scattered to broken.	maritime Polar
6	Mar	------	38.0	36.0	------	2.0	Overcast	maritime Polar
7	Apr	45.5	48.0	27.0	18.7	21.5	Overcast	maritime Arctic
8	Apr	33.0	34.0	29.0	4.0	5.0	Scattered	maritime Arctic
9	July	37.0	39.0	32.5	4.5	6.5	Broken	maritime Polar
10	Aug	20.0	36.0	32.5	−12.5	3.5	Broken	maritime Polar
11	Sept	38.0	42.0	36.7	1.3	5.3	------	maritime Tropical
12	Sept	21.0	40.0	37.0	−16.0	3.0	Overcast	maritime Polar
13	Oct	35.0	36.0	31.0	4.0	5.0	Scattered	maritime Polar
14	Oct	35.0	------	33.5	1.5	------	Scattered	maritime Polar
15	Oct	40.0	------	30.5	9.5	------	Scattered	maritime Polar
16	Oct	41.0	42.0	34.0	7.0	8.0	Broken	maritime Polar
17	Nov	33.0	38.0	34.8	−1.8	3.2	Scattered	maritime Polar
18	Nov	20.0	39.5	37.5	−17.5	2.0	Scattered	maritime Polar
19	Dec	31.0	31.0	25.5	5.5	5.5	Scattered	maritime Arctic

then advected across the thermal field. Under such circumstances there would tend to be a maximum of occurrence of cirrus whose base temperature is in the vicinity of −40° C. Ogives were drawn giving cumulative cirrus occurrence versus temperature of cloud base to see whether a maximum in slope existed near −40° C. Figure 3 gives the ogive for November-March-April. This curve is typical and reveals a weak maximum in its slope between −40° C. and −45° C. Similar results were obtained for the other curves and these are listed in table 8. These results imply a small tendency for the base of cirrus to be found with increased frequency in the vicinity of −40° C.

From the ogive curves it can be deduced that 70 percent or more of cirrus layers for a given season lie with their bases within a 10,000-ft. range. The Project Cloud Trail Report [7] indicates even higher percentages. Thus an estimate of the cloud base at a mean position should give an average accuracy of close to 3,000 ft. As a result, any curves which give estimates in the vicinity of mean base heights should give similar accuracy.

10. TOPS OF CIRRUS LAYERS AND THE TROPOPAUSE

An analysis was carried out to see whether there was any significant relationship between the tops of cirrus layers and the tropopause. The results of this analysis are summarized in table 9 and these indicate that the separation between the tropopause and cloud tops varies a good deal but is least in the cold months and with overcast layers. French and Johannessen [8] found a somewhat closer relationship between cirrus tops and the tropopause.

11. STRATOSPHERIC CIRRUS

From table 9 it is apparent that cirrus is largely confined to the troposphere. However, in view of the interest in

TABLE 11.—*Visibility in cirriform cloud*

Visibility less than	1 mile	½ mile	¼ mile
Percentage	70	60	30

stratospheric humidity, those cases which penetrated at least 2,000 ft. into the stratosphere were investigated. Approximately 5 percent of the cases fell into this category and the pertinent data on these are given in table 10. Owing to the errors involved, a few of these instances may be, in actuality, tropospheric cloud but for the most part the reports seem to be authentic stratospheric cirrus. Most of the cases involved scattered cloud in the lower stratosphere above maritime Polar tropopause. Thus, some of this cloud may have formed in tropical tropospheric air which was absorbed into the stratosphere through a break or fold in the tropopause.

12. VISIBILITY IN CIRRUS CLOUD

Approximately 40 reports were obtained of visibility in cirriform cloud. Many of these reports were only rough estimates so that the results of this analysis (table 11) can be depended upon to give only an order of magnitude.

ACKNOWLEDGMENTS

Thanks are due to Miss Nancy Kelsey who assisted with the abstraction of the temperature data. This paper is published by permission of the Director, Meteorological Branch, Department of Transport, Canada.

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